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The effect of standard lumbar discectomy on segmental motion: 5-year follow-up using radiostereometry

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Abstract We measured the effects of lumbar discectomy on segmental motion over a period of 5 years. Twenty-four patients with lumbar disc herniation were treated by standard lumbar discectomy at the L4–L5 or L5–S1 level. Peroperatively, tantalum markers were inserted into L4, L5, and the sacrum. Radiostereometric analysis was performed at discharge from hospital and 5 years postoperatively. The treated level was compared with the corresponding untreated level. Thus, patients who had discectomy at the L4–L5 level served as controls for patients with L5–S1 lesions and vice versa. The relative rotation and translation in relation to the three cardinal axes were calculated. Inducible displacements over the two discs were calculated between the supine and standing positions. At the L4–L5 level, there were no differences in inducible displacements between the operated and control levels at discharge or 5 years postoperatively. At the L5–S1 level we found decreasing inducible movement in the sagittal plane over time for discectomy patients. The reason for decreasing mobility over time after discectomy at the L5–S1 but not at the L4–L5 level is unknown. Mechanical factors caused by the more vertical orientation of the L5–S1 disc in combination with degenerative changes could be one explanation.

Résumé Nous avons mesuré les effets de la discectomie lombaire sur la mobilité segmentaire sur une période de 5 années. Vingt-quatre malades avec une hernie discale lombaire ont été opérés par discectomie standard au niveau L4–L5 ou L5–S1. Des marqueurs en tantale ont été insérés en peropératoire dans L4, L5 et le sacrum. L'analyse radiostéréométrique a été exécutée à la sortie de l'hopital et 5 ans après l'intervention. Le niveau opéré a été comparé avec le niveau non-opéré correspondant. Donc, les malades opérés sur L4–L5 ont servi comme contrôles pour malades opérés sur L5–S1 et vice versa. La rotation et la translation relatives selon les trois axes cardinaux ont été calculées. Les déplacements induits sur les deux disques ont été calculés entre les positions debout et couché sur le dos. Sur L4/L5 il n'y avait pas de différences dans les déplacements induits entre les opérés et le contrôle initial ou 5 ans aprés. Sur L5/S1 nous avons trouvé avec le temps des mouvements induits décroissants dans le plan sagittal pour les malades opérés. La raison de la mobilité décroissante avec le temps après discectomie L5–S1 mais pas au niveau L4–L5 est inconnue. Les facteurs mécaniques en relation avec l'orientation plus verticale du disque L5–S1, en association avec l'évolution dégénérative pourraient être une explication.

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Introduction

Lumbar disc herniation is a common spinal disorder with an estimated 1-year incidence of 0.1–0.5% [6]. Failure of conservative treatment requires surgical treatment usually by open discectomy. The effect of lumbar discectomy on segmental stability has been studied experimentally, but there is a lack of clinical studies. A cadaver specimen study showed that total discectomy resulted in significantly more angular motion in all directions when compared to subtotal discectomy [4]. In another cadaver study the specimens were treated by fenestration and discectomy at the L3–S1 levels. Lumbar stability was affected only in the sagittal plane with increased vertical and horizontal motion [10].

In clinical practice radiography is the standard method to measure movement of a vertebral segment [2, 3]. Using flexion–extension examinations the precision of measurement may reach 1.0–2.3° with respect to rotation around the transverse axis and 0.6–1.2 mm in anterior–posterior translation, provided that so-called distortion compensated roentgen analysis is employed [9]. MRI has evolved as an alternative for dynamic examination of the lumbar spine.

The precision of this method is still uncertain [15, 16]. Johnsson et al. [5] used radiostereometric analysis (RSA) in a study of noninstrumented distal lumbar fusions. The measurement accuracy for translation was 0.2–0.6 mm depending on direction but rotation was not calculated. In a clinical study with biplanar radiography before and 3 months after discectomy, an abnormally large lateral bend or axial rotation at the level immediately above the one later subjected to surgery was found. This abnormal motion decreased after the operation [14]. The authors concluded that discectomy with minimal resection of the laminae did not produce instability but follow-up was restricted to 3 months. Thus, the long-term effects of a lumbar discectomy on segmental stability are not known.

We measured the inducible displacement of a lumbar discectomy segment postoperatively and again after 5 years using RSA. We hypothesized that lumbar disc herniation treated by standard lumbar discectomy does not affect the segmental motion over time.

Patients and methods

Between January 1994 and August 1995, 14 men and ten women, mean age 36 (SD 12) years, with lumbar disc herniation at the L4–L5 or L5–S1 level requiring surgery were included. Patients with additional spinal disease were excluded. Sixteen patients were examined and treated by one surgeon (P.N.) whereas five other spine surgeons treated the remaining eight patients. The local hospital ethical committee approved the study. All patients gave their informed consent for participation. There were ten operations at the L4–L5 level and 14 at the L5–S1 level. Straight leg raising was restricted in all but one of the patients with L4–L5 level disc herniation. The duration of preoperative sciatica was 4 (1–16) months. The indication for surgery of lumbar disc herniation at our clinic was persistent severe sciatica after at least 6 to 8 weeks of conservative treatment and a CT/MRI-verified disc herniation that correlated to the clinical picture.

Surgical procedure

The operation started with percutaneous insertion of five to seven tantalum markers (∅ 0.8 or 1.0 mm) into the posterior parts of the L3, L4, L5, and sacrum using fluoroscopy. After skin incision the paravertebral muscle was dissected down to the laminae. The interlaminar ligament was resected. A partial laminotomy was performed if necessary. Loose material from the intervertebral disc was removed; i.e., a true discectomy was not performed. The width of the lateral recess and root canal was evaluated with probes. Postoperatively, the patients were allowed to walk without any external support from the first postoperative day. They were advised to avoid hip flexion of more than 70° and to avoid carrying loads the first 6 postoperative weeks [11].

Radiostereometry

RSA examinations were performed in the supine and standing positions at discharge (after mobilization) and 5 years postoperatively using the uniplanar method [8]. Two roentgen tubes with central beams crossing at about 35° at the level of the lumbar spine were used for simultaneous exposure of a pair of radiographs. A reference Plexiglas cage (RSA Biomedical Innovations, Umeå, Sweden) fitted with tantalum markers was placed between the patient and the radiographic films. Most postoperative films were measured using a measuring table (manual measurements). The remaining examinations were measured using a digital technique 300 DPI [1]. The cage markers defined the laboratory coordinate system and were used to calculate the position of the radiographic foci. Subsequently, the three-dimensional coordinates of the patient markers were determined at each examination.

For the mathematical evaluation of the radiographic examinations, we used a software package UmRSA (RSA Biomedical Innovations). Segments analyzed were the L4–L5 and L5 sacrum using the more distal level as fixed reference segment. The relative rotation in degrees and translation into millimeters in relation to the three cardinal axes were calculated. The patients were examined supine and standing. The motion of each segment between those two positions (inducible displacement) was computed. Comparisons were made between treated and untreated segments at the same level. Thus, patients who had discectomy at the L5–S1 level served as controls for the patients with lesions at the L4–L5 level and vice versa. Change of inducible displacement over time was also analysed.

To achieve standardized measurements of translation, a so-called fictive point was plotted at the centre of the L4 and L5 vertebral body in each patient. The location of this point was transferred to the 5-year postoperative examinations using the known positions of each tantalum marker configuration in the two respective vertebrae [12]. The 3D translation of this central point in the vertebral body was computed for L4 relative to a fixed L5 and for L5 relative a fixed sacrum. By this procedure measurements of translations were done at comparable positions between patients and became less dependent on the positions of the tantalum markers.

The reproducibility of the RSA was evaluated by repeating the examinations in 11 patients (31 segments from L4 to the sacrum) after an interval of 5–10 min. Based on these double examinations, the 99% confidence intervals for significant motion was calculated (Table 1). These tests included both the precision of the RSA technique and any variations due to inconsistencies caused by repetition of the supine-to-standing transfer in the individual patient. They were based on the manual measurement technique with inferior precision [1].

Table 1 Confidence interval (99%) for significant motion on L4–L5 and L5–S1 segments

Type of motion	SD	99% confidence limit
Rotations (°)		
Transverse axis	0.91	2.74
Longitudinal axis	0.31	0.88
Sagittal axis	0.38	1.08
Translations (mm)		
Transverse axis	0.33	0.95
Longitudinal axis	0.21	0.61
Sagittal axis	0.33	0.93

Follow-up

Three of 24 patients had to be excluded: one due to insufficient numbers of tantalum markers, one with a sacralized L5 vertebra, and one who was not examined with RSA at discharge. Five years postoperatively five further patients were not available for RSA. One patient required spinal fusion 3 years after the index operation, one had died, and three had moved and were lost to follow-up. Thus, 16 patients were examined with RSA both at discharge and 5 years postoperatively; eight were treated for L4–L5 lesions and eight for L5–S1 lesions. In three of these patients, motion over one of the segments could not be studied (one control, one L4–L5 lesion, and one at L5–S1) because of marker loosening (Tables 2, 3).

Statistical methods

Wilcoxon signed ranks test, Mann–Whitney' test and Spearman's rho were used. The significance level was set at <0.05.

Results

Motion over the same segment—postoperatively versus 5 years

The development of inducible displacements over the control and treated segments were studied separately comparing changes over a 5-year period (e.g., "natural course" and effects of surgery, respectively).

L4–L5 level

The pattern of inducible displacement did not differ between the examination at discharge and at 5 years in either the control segments (p=0.21–0.89) or the discectomy segments (p=0.5–1.0, Wilcoxon signed rank test, Table 2).

L5–S1 level

At the control segments no significant differences in inducible displacement were found (p=0.06–0.92, Table 2). At the treated L5–S1 segments there was significantly less

Table 2 Development of inducible rotation and translation over 5 years. Control and treated segments analyzed separately

	Controls		Discectomy	
	At discharge	5 years postoperatively	At discharge	5 years postoperatively
L4–L5	n=8		n=7	
Rotation (°)				
Transverse axis (−lordosis, +kyphosis)	−0.3 (−1.0, 0.8)	−0.6 (−2.9, 1.2)	0.0 (−4.0, 5.1)	−0.5 (−4.0, 4.0)
Longitudinal axis (+left, −right rotation)	0.0 (−0.7, 0.4)	0.3 (−1.0, 0.7)	0.3 (−0.5, 1.7)	0.2 (−0.3, 0.5)
Sagittal axis (−left tilt, +right tilt)	0.3 (−0.9, 2.0)	−0.8 (−2.6, 1.0)	−0.8 (−2.2, 2.3)	−0.7 (−2.1, 1.0)
Translation (mm)				
Right–left (−right, +left)	0.0 (−0.8, 0.5)	0.4 (−0.7, 1.0)	0.4 (−0.8, 1.6)	0.4 (−0.3, 1.3)
Proximal–distal (−distal, +proximal)	−0.5 (−0.5, −0.3)	−0.4 (−1.9, 0.1)	−0.5 (−2.1, −0.3)	−0.4 (−1.6, 2.8)
Anterior–posterior (−posterior, +anterior)	0.2 (−0.4, 0.8)	0.1 (−1.0, 0.5)	0.0 (−4.2, 2.0)	−0.2 (−4.0, 1.3)
L5–S1	n=7		n=7	
Rotation (°)			**	
Transverse axis (−lordosis, +kyphosis)	1.9* (0.4, 2.4)	0.7* (−2.9, 1.2)	3.7** (−0.2, 4.3)	1.5** (−0.4, 2.9)
Longitudinal axis (+left, −right rotation)	−0.1 (−0.7, 0.6)	0.2 (−2.3, 0.6)	−0.1 (−0.2, 0.5)	0.1 (−0.2, 0.5)
Sagittal axis (−left, +right tilt)	−0.2 (−1.6, 1.6)	−0.4 (−2.0, 4.7)	−0.1 (−0.3, 0.7)	0.1 (−0.5, 0.6)
Translation (mm)				
Right–left (−right, +left)	0.1 (−0.5, 0.4)	0.3 (−0.3, 0.8)	0.1 (−0.2, 0.2)	−0.2 (−0.5, 0.1)
Proximal–distal (−distal, +proximal)	−0.5 (−1.5, 1.6)	−0.5 (−3.3, −0.1)	−0.8*** (−1.3, −0.6)	−0.5*** (−0.7, 4.5)
Anterior–posterior (−posterior, +anterior)	0.2 (−0.5, 0.7)	0.1 (−0.3, 0.5)	0.8 (−0.2, 2.7)	0.5 (0.1, 4.9)

Values representing median (range)
n Number of available segments
*p=0.06, Wilcoxon signed ranks test
**p=0.06, Wilcoxon signed ranks test
***p<0.02, Wilcoxon signed ranks test

Table 3 Comparison of inducible rotation and translation of control versus discectomy segments. Separate analysis at discharge and 5 years postoperatively

	At discharge		5 years postoperatively	
	Controls	Operated	Controls	Operated
L4–L5	*n*=11	*n*=10	*n*=8	*n*=7
Rotation (°)				
Transverse axis (−lordosis, +kyphosis)	−0.4 (−2.8, 0.8)	−0.7 (−5.3, 5.1)	−0.6 (−2.9, 1.2)	−0.5 (−4.0, 4.0)
Longitudinal axis (+left, −right rotation)	0.0 (−0.7, 0.4)	0.3 (−0.5, 1.8)	0.3 (−1.0, 0.7)	0.2 (−0.3, 0.5)
Sagittal axis (−left tilt, +right tilt)	0.2 (−2.4, 2.0)	−0.2 (−2.1, 2.6)	−0.8 (−2.6, 1.0)	−0.7 (−2.1, 1.0)
Translation (mm)				
Right–left (−right, +left)	0.1 (−0.8, 0.6)	0.2 (−0.8, 1.6)	0.4 (−0.7, 1.0)	0.4 (−0.3, 1.3)
Proximal–distal (−distal, +proximal)	−0.5 (−0.8, −0.3)	−0.5 (−2.1, −0.3)	−0.4 (−1.9, 0.1)	−0.4 (−1.6, 2.8)
Anterior–posterior (−posterior, +anterior)	0.2 (−0.4, 0.8)	0.0 (−4.1, 2.0)	0.1 (−1.0, 0.5)	−0.2 (−4.0, 1.3)
L5–S1	*n*=9	*n*=10	*n*=7	*n*=7
Rotation (°)				
Transverse axis (−lordosis, +kyphosis)	1.9 (0.4, 4.8)	2.8 (−0.2, 5.8)	0.7 (−2.9, 1.2)	1.5 (−0.4, 2.9)
Longitudinal axis (+left, −right rotation)	−0.1 (−0.7, 0.6)	−0.1 (−0.3, 0.5)	0.2 (−2.3, 0.6)	0.1 (−0.2, 0.5)
Sagittal axis (−left, +right tilt)	−0.2 (−1.6, 1.6)	−0.2 (−0.9, 0.7)	−0.4 (−2.0, 4.7)	0.1 (−0.5, 0.6)
Translation (mm)				
Right–left (−right, +left)	0.1 (−0.5, 0.8)	0.1 (−0.2, 0.2)	0.3* (−0.3, 0.8)	−0.2* (−0.5, 0.1)
Proximal–distal (−distal, +proximal)	−0.7 (−2.5, 1.6)	−0.8 (−1.4, 0.0)	−0.5 (−3.3, −0.1)	−0.5 (−0.7, 4.5)
Anterior–posterior (−posterior, +anterior)	0.2** (−0.5, 1.3)	1.0** (−0.2, 2.7)	0.1*** (−0.3, 0.5)	0.5*** (0.1, 4.9)

Values representing median (range)
n Number of available segments
*p=0.02, Mann–Whitney test
**p<0.02, Mann–Whitney test
***p=0.09, Mann–Whitney test

axial compression between supine and standing at the 5-year follow-up (p<0.02). The other motion parameters seemed to remain unchanged (p=0.06–0.73, Table 2).

Motion after discectomy versus control segment at discharge and 5 years postoperatively

The influence of surgery was studied by comparison between the inducible displacement over the discectomy and the corresponding control segment at discharge and 5 years postoperatively.

L4–L5 level

At the L4–L5 level the inducible displacements did not differ between discectomy and control levels at discharge (p=0.26–0.94) or at the 5-year follow-up (p=0.49–1.00, Table 3).

L5–S1 level

At the L5–S1 level there was increased inducible translation in treated patients. Between supine and standing at discharge, the L5 displaced almost 1 mm more anteriorly (p<0.02). At 5 years there was no difference (p=0.09). At this time the L5 also displaced in a different direction along the left–right axis in the surgically treated group. The discectomy patients showed mainly a displacement of the L5 vertebra to the right whereas there was a corresponding displacement mainly to the left in the controls (p=0.02). This displacement did not differ depending on the side of the disc herniation (p=0.6). The other motion parameters did not differ (p=0.14–0.93, Table 3).

Discussion

In an autopsy study Kirkaldy-Willis and Farfan [7] described three stages in the degenerative process of the lumbar spine. The first stage is temporary dysfunction, i.e., small damage with subsequent healing. The middle stage is associated with increased mobility with an established degeneration, followed by stage three when the mobility decreases and finally results in a fixed deformity. Lumbar disc herniation is a manifestation of degenerative disc disease, which we believe should mainly be linked to stage one or two. Mobility, which in our study was evaluated as inducible motion, can be anticipated to decrease should the process progress to a fixed deformity. According to these theories, patients with lumbar disc herniation will develop decreasing mobility of the affected disc segment over time, re-

gardless of whether there has been any surgical treatment. The influence of the surgical procedure is unclear. In a cadaver study, Lu et al. [10] observed increased motion in the sagittal plane after multilevel fenestration but they performed a total discectomy, making any definite conclusions about posterior destabilization of the spine due to surgery uncertain.

The pattern of motion differed between the two studied levels (L4–5 and L5–S1) when the patients changed from supine to the standing position. This difference related to the level examined indicates that segmental instability in the lower lumbar spine has to be analysed level by level. The reason for this variation is not known, but the more vertical position of the L5 vertebra compared to the L4 vertebra in the standing position is probably important.

We found that the inducible displacement in L4–L5 segments subjected to surgery remained almost unchanged over a 5-year period whereas the axial compression between L5 and S1 decreased with time. Our observation suggests that the surgically treated L5–S1 segments lose more elasticity over the 5 years of observation than the control discs, probably because of stiffening of the ligaments and degenerative changes of the intervertebral joints. The reason for early postoperative increased anterior slipping of L5 between supine and standing is not known. It could be due to decreased ligament tension following removal of disc material and partial resection of the interspinal ligaments. It may also reflect a later stage of disc degeneration in conjunction with the more vertical position of this segment. At 5 years this difference could no longer be demonstrated, probably reflecting stiffening of the disc segment. The stability of the L4–L5 segment over time could indicate less degeneration than the L5–S1 level during the study period or might, as suggested above, reflect the more horizontal position of the L4–L5 disc. In the control discs the inducible displacement did not change over the observation period. If age-related disc change is associated with decreasing mobility, this process seems to be slow within the age limits of our study population.

Our use of the untreated level as control could be questioned because the motion at this level might not be "normal" due to the adjacent discectomy. Postoperatively, the motion might have been less because of increased muscular tension. Increased muscular tension could also influence the motion of the operated segment. Thus, both the control and operated segments have probably been subjected to about the same muscular tension at the postoperative examination.

The precision for the RSA method is high. We present values on both rotation and translation with a 99% confidence interval, *including* variations caused by inconsistent motion between the vertebrae and repeated examinations. These figures cannot therefore be compared to corresponding values previously presented in studies on fusion.

Stokes et al. have previously found a "splinting" of levels with symptomatic lumbar disc herniations and therefore we did not perform preoperative RSA examinations [13]. As in previous RSA studies of the lumbar spine, ours included comparatively few patients, which limits the conclusions to be drawn. Our findings do, however, indicate that over 5 years, the motion at the L4–L5 segment undergoes little or no change, regardless of whether or not there has been a partial discectomy. At the L5–S1 level patients following discectomy changed their pattern of inducible displacement between discharge and the 5-year follow-up. Whether the surgical procedure and/or proceeding degeneration caused this difference could not be established.

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